US009341061B2

(12) **United States Patent**
Kennedy et al.

(10) **Patent No.: US 9,341,061 B2**
(45) **Date of Patent: *May 17, 2016**

(54) **METHOD OF OPENING A MINE DOOR LEAF**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/321,408**

(22) Filed: **Jul. 1, 2014**

(65) **Prior Publication Data**

US 2014/0311042 A1 Oct. 23, 2014

Related U.S. Application Data

(63) Continuation of application No. 12/708,948, filed on Feb. 19, 2010, now Pat. No. 8,800,204.

(51) **Int. Cl.**
E21F 1/10 (2006.01)
E21F 1/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***E21F 1/10*** (2013.01); ***E05F 15/614*** (2015.01); ***E05F 15/627*** (2015.01); ***E05F 15/63*** (2015.01); ***E06B 7/04*** (2013.01); ***E21F 1/12*** (2013.01); *E05Y 2201/224* (2013.01); *E05Y 2201/624* (2013.01); *E05Y 2201/626* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC E05F 15/63; E05F 15/627; E05F 15/614; E06B 7/04; E06B 2003/7052; E06B 3/362; E21F 1/10
USPC 49/116, 118, 138, 340, 341, 345, 366, 49/367, 276, 277, 339, 506
See application file for complete search history.

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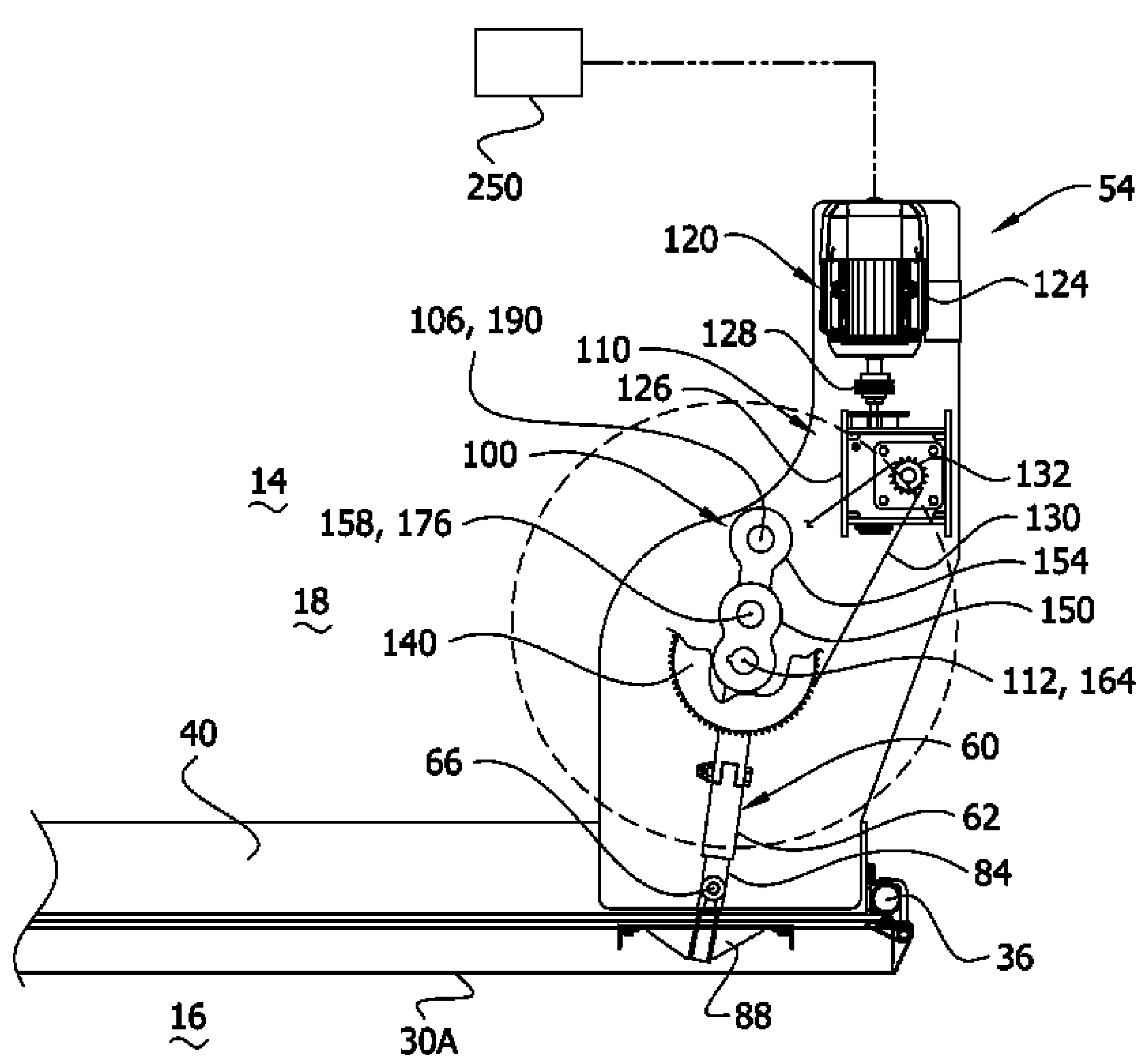
(74) *Attorney, Agent, or Firm* — Senniger Powers LLP

(57) **ABSTRACT**

A method of opening a mine door leaf installed in a mine passageway having a high pressure zone and a low pressure zone. The method includes the steps of operating a variable-throw crank mechanism in a first configuration having a first crank length to apply a first force to the mine door leaf to move at a first speed, operating the variable-throw crank mechanism in a second configuration having a second crank length less than the first crank length to apply a second force greater than the first force to the mine door leaf to move at a second speed slower than the first speed, and using a resistance pressure associated with the high and low pressure zones in the mine passageway to convert the variable-throw crank mechanism from the first configuration to the second configuration.

19 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

E06B 7/04	(2006.01)
E05F 15/614	(2015.01)
E05F 15/627	(2015.01)
E05F 15/63	(2015.01)
E06B 3/36	(2006.01)
E06B 3/70	(2006.01)

(52) **U.S. Cl.**

CPC *E05Y2201/644* (2013.01); *E05Y 2800/37* (2013.01); *E05Y 2800/71* (2013.01); *E05Y 2900/11* (2013.01); *E05Y 2900/116* (2013.01); *E05Y 2900/132* (2013.01); *E05Y 2900/40* (2013.01); *E06B 3/362* (2013.01); *E06B 2003/7057* (2013.01)

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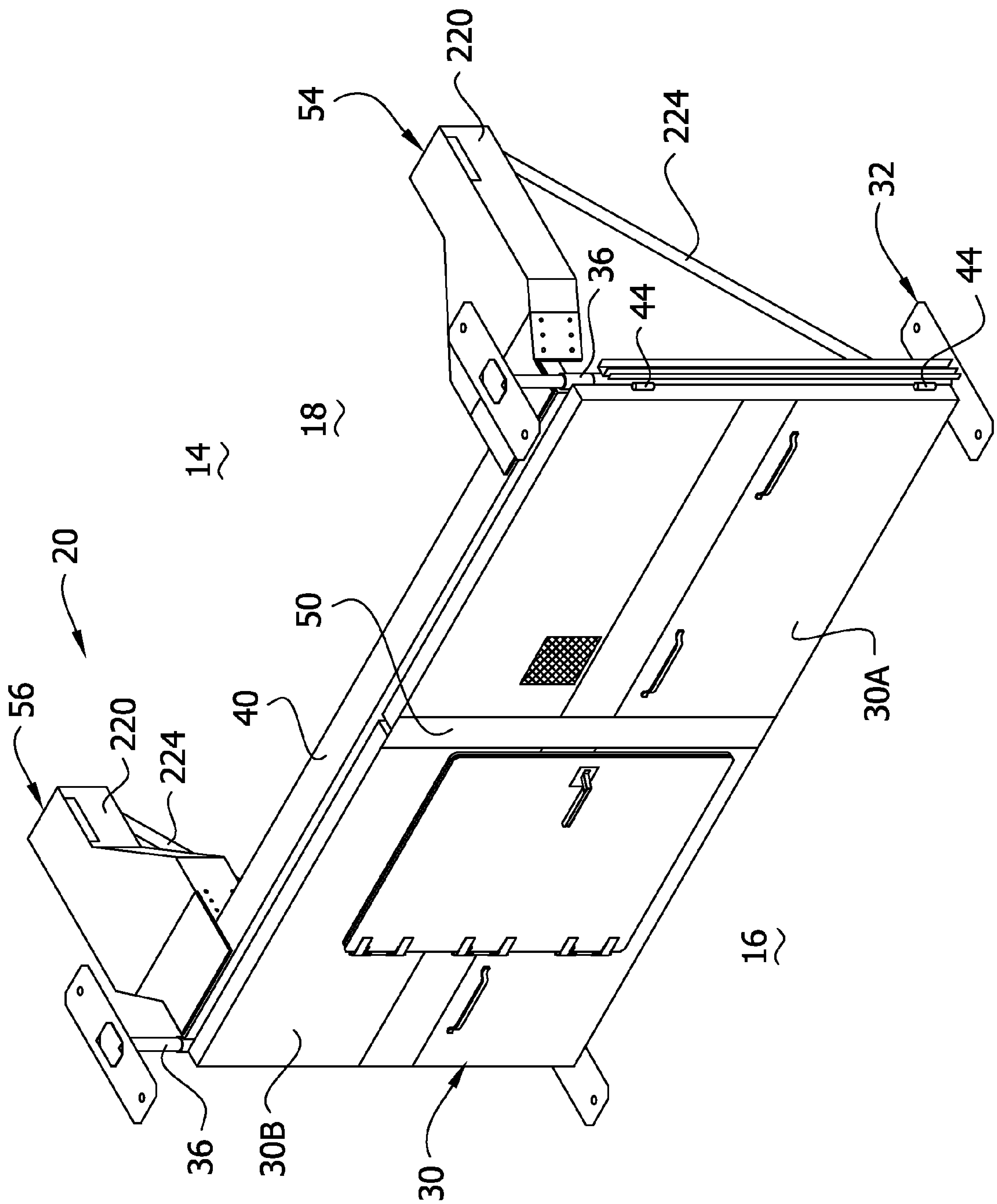
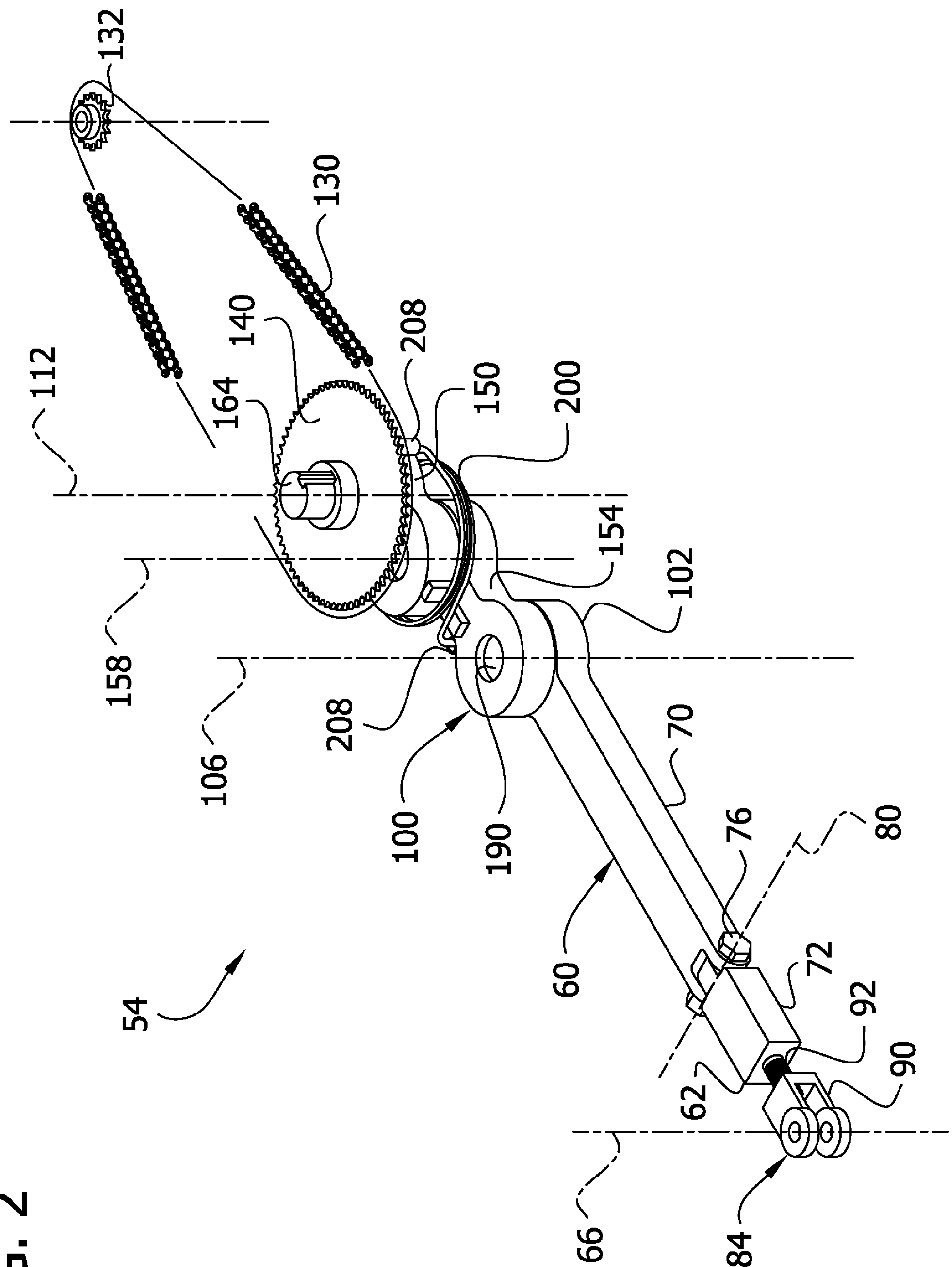


FIG. 1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130
112
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164
208
150
200
154
102
158
106
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70
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190
76
80
54
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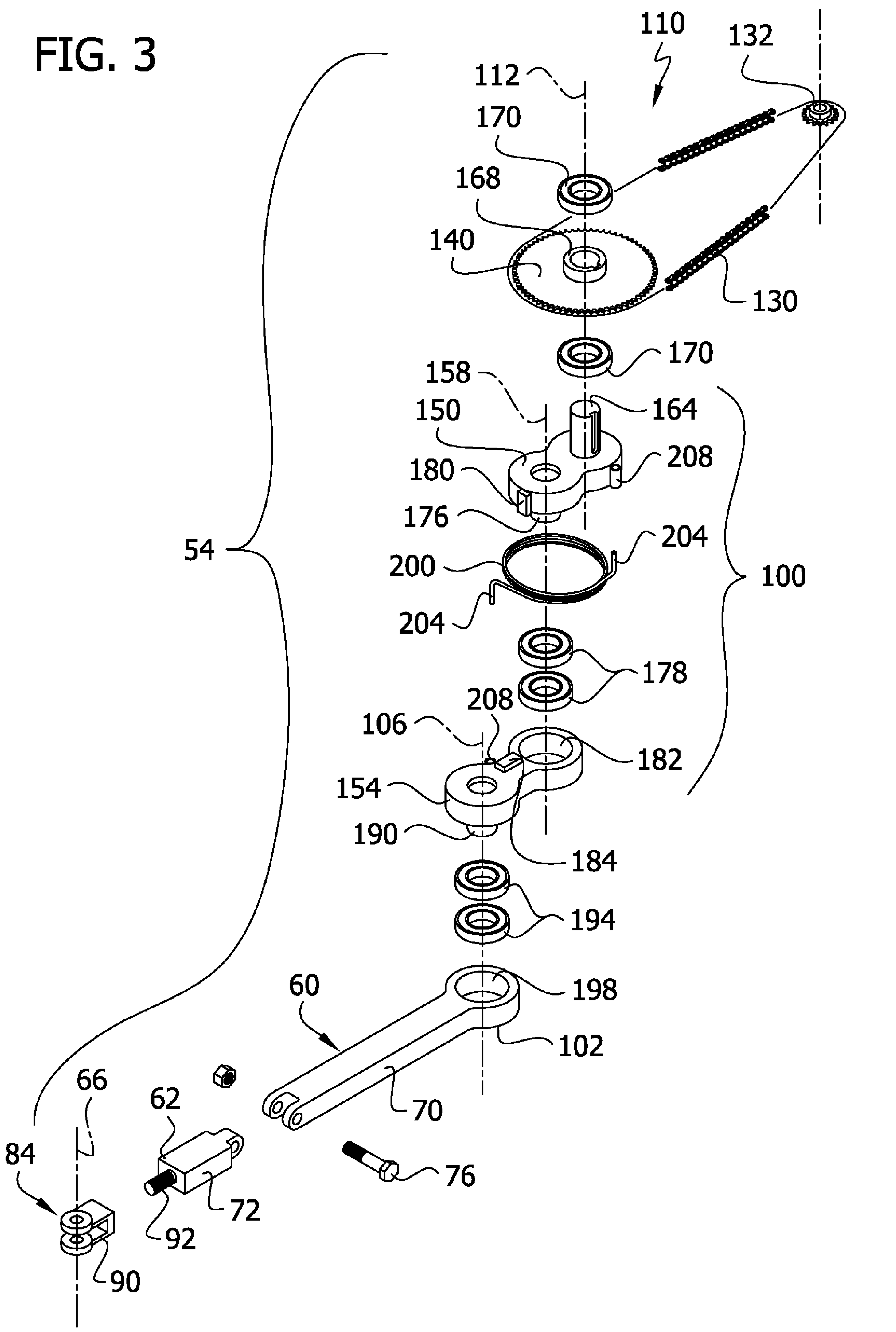
72
92
90
62
66
84

FIG. 2

FIG. 3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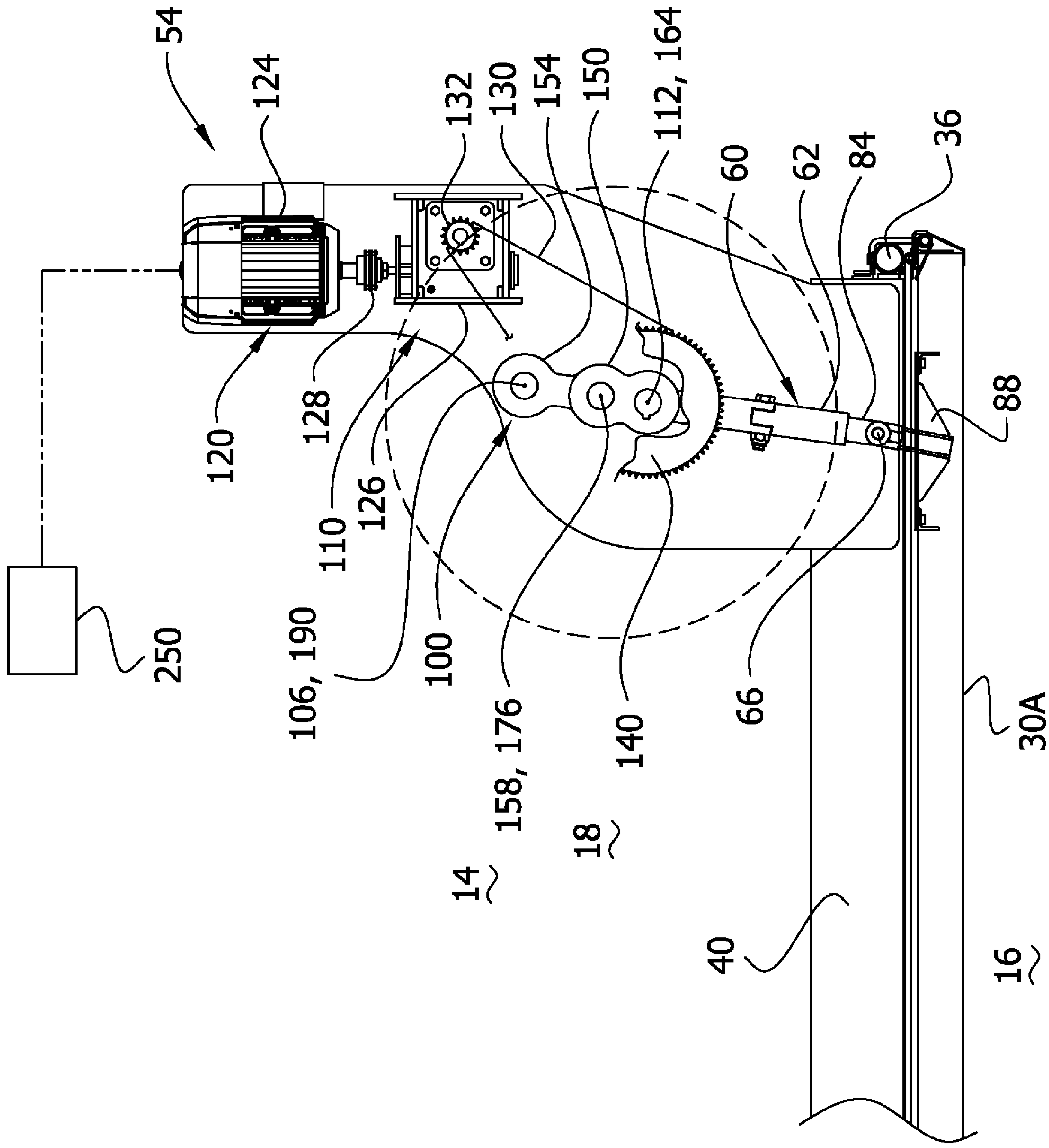
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124
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154
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112, 164
60
62
84
36
88
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140
66
250
30A
18
14
40
16

FIG. 4

FIG. 4A

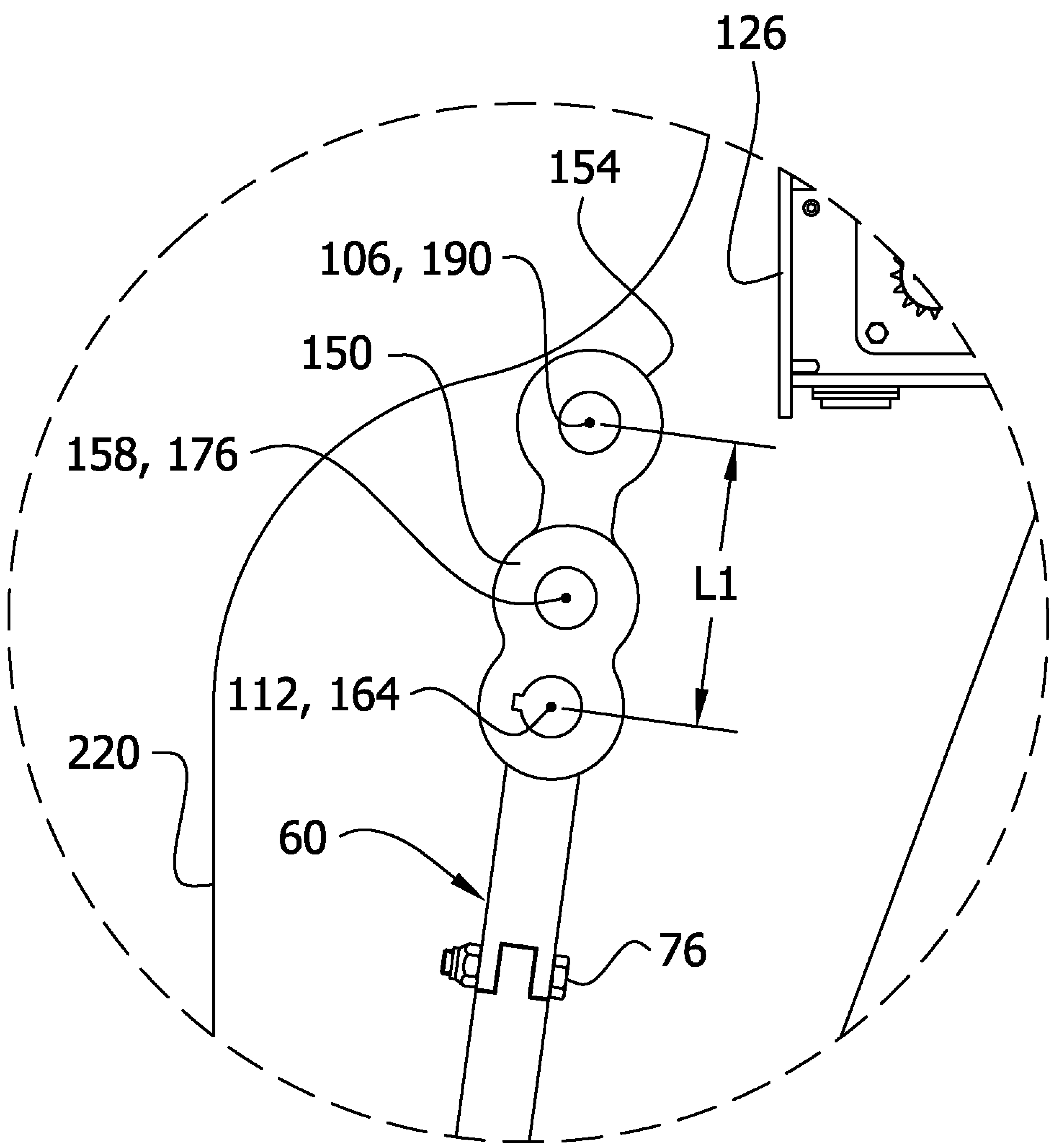
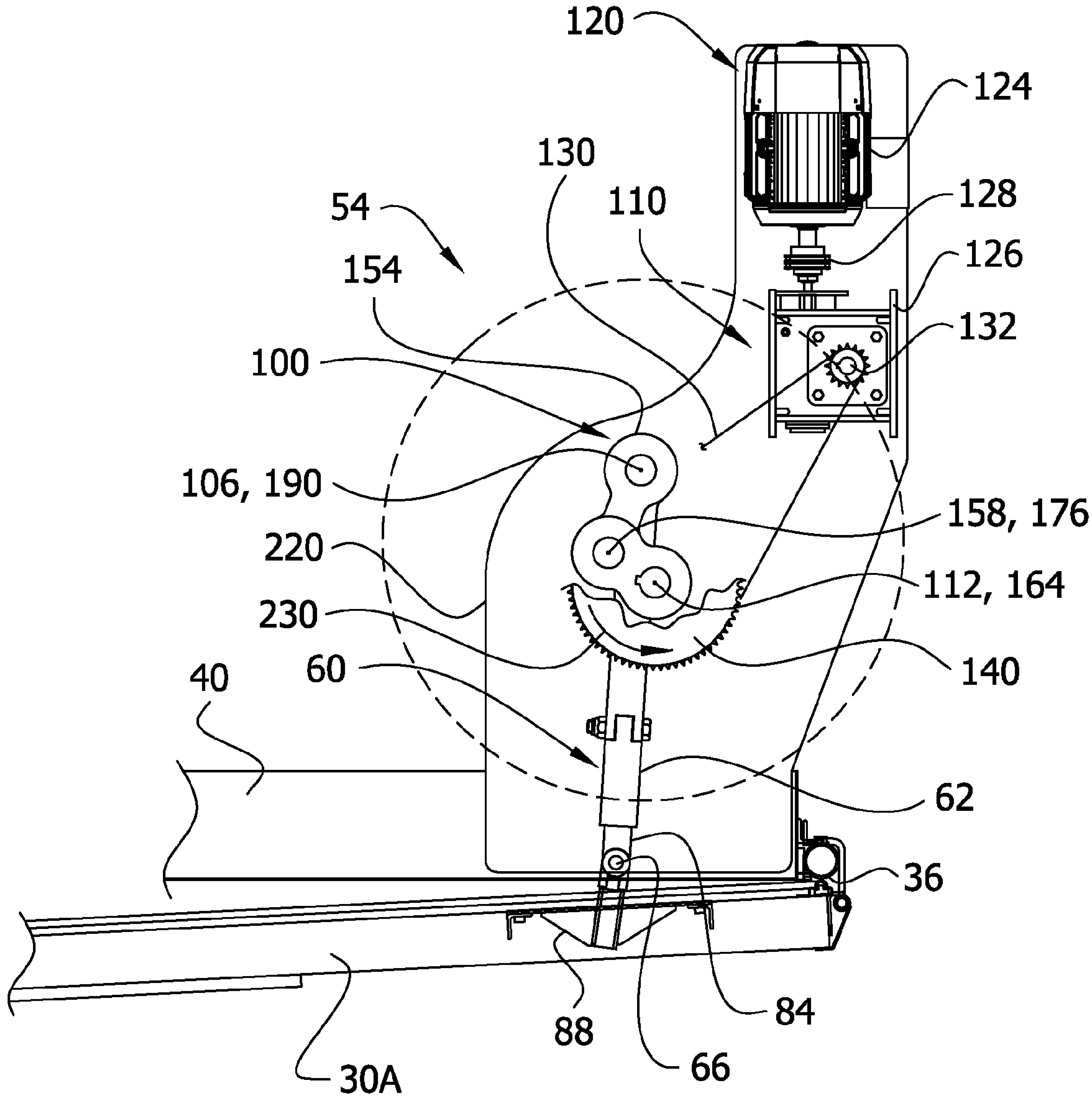


FIG. 5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30A

FIG. 5A

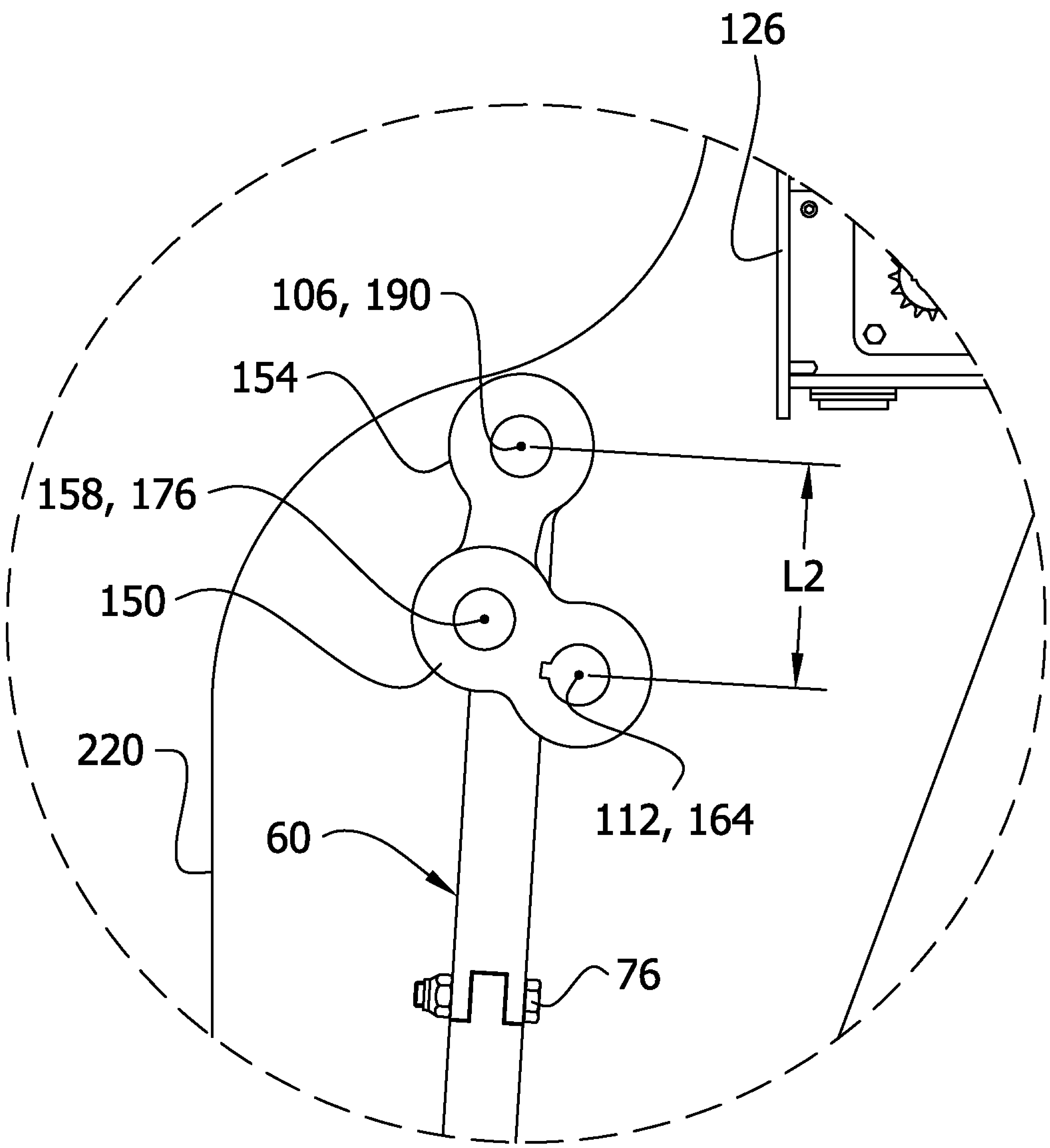
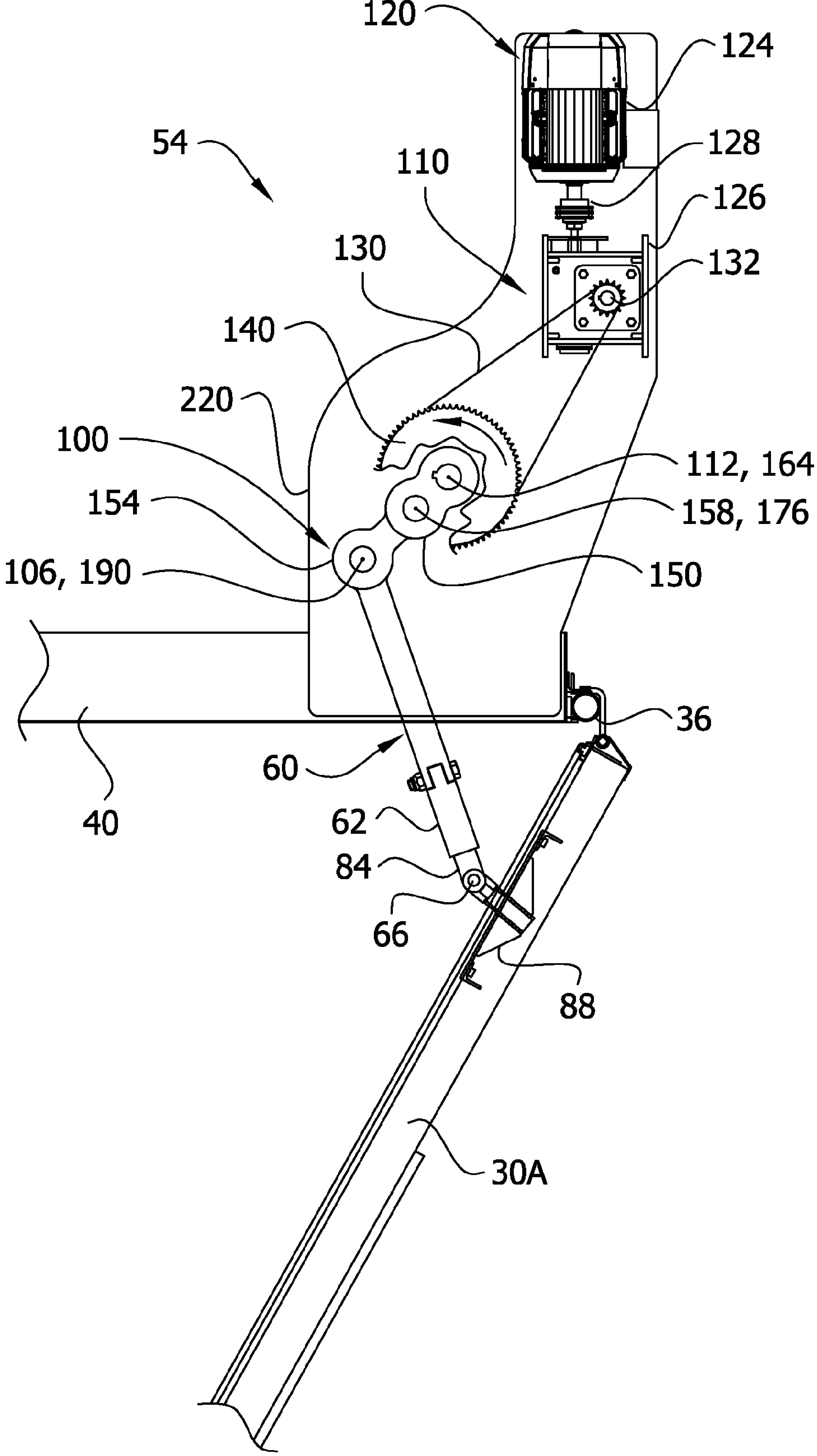


FIG. 6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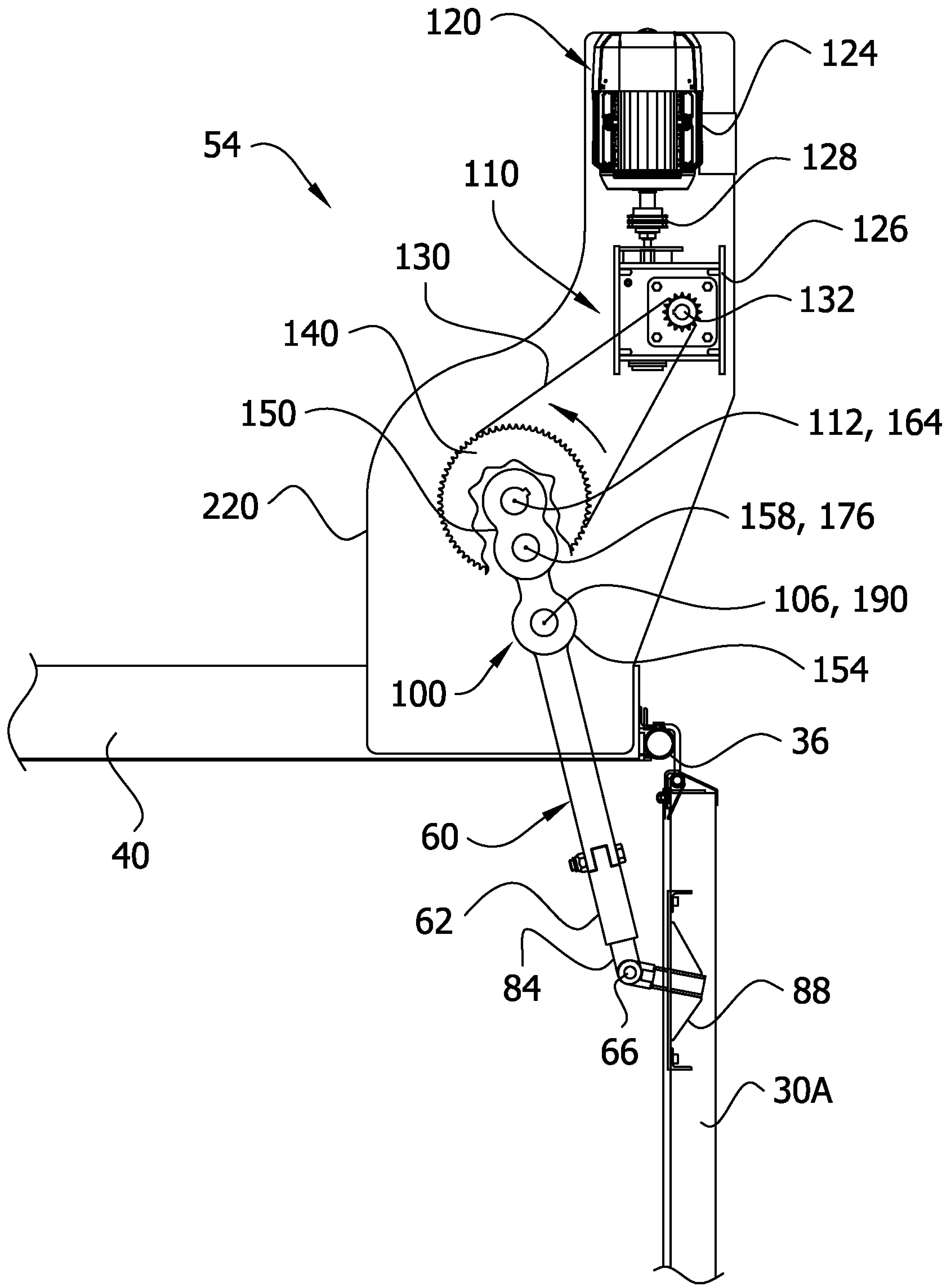
30A

FIG. 7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30A

FIG. 8

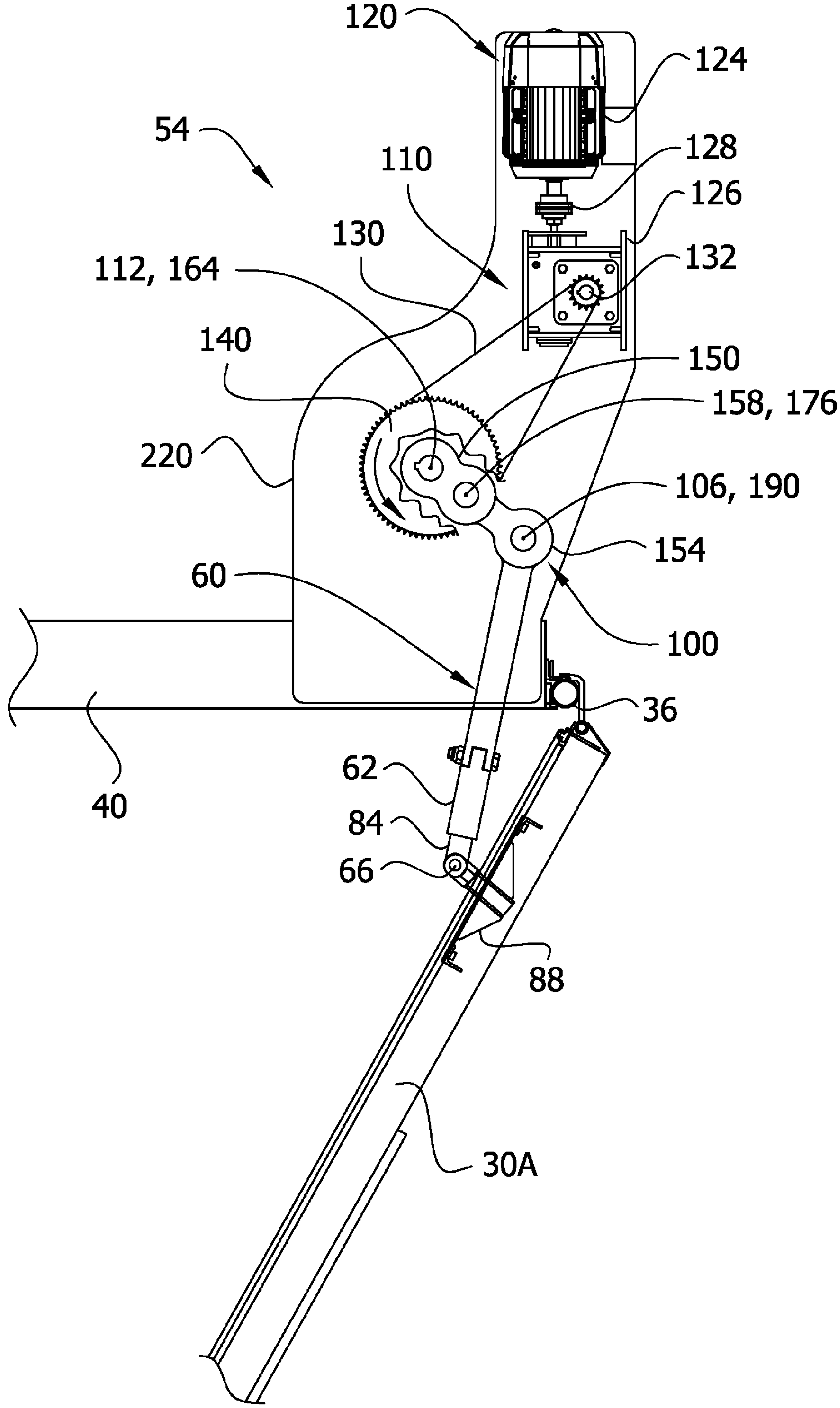
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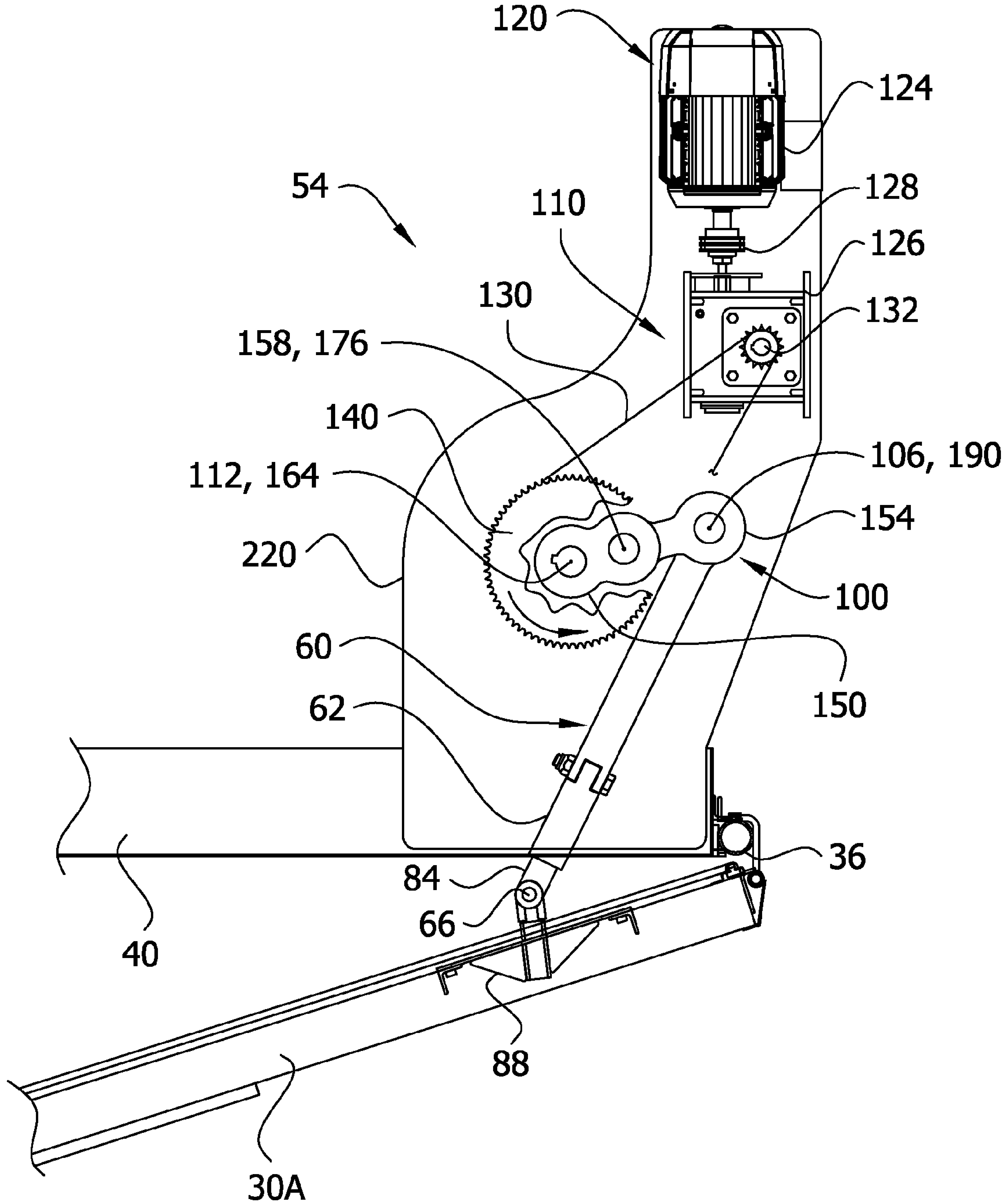
FIG. 9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METHOD OF OPENING A MINE DOOR LEAF

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 12/708,948, filed Feb. 19, 2010 now U.S. Pat. No. 8,800,204, the entire contents of which is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention generally relates to mine ventilation equipment, and more particularly to a mechanism for opening a mine door.

BACKGROUND OF THE INVENTION

Mine doors are frequently used throughout a mine to control ventilation. The doors are typically large and heavy, and they are often opened and closed using hydraulic or pneumatic mechanisms. Examples of such mechanisms are described in U.S. Pat. Nos. 6,425,820, 6,938,372 and 7,118,472. While such mechanisms are generally reliable, they do have certain drawbacks, including complexity and expense. Also, since mine doors are very heavy and subject to large opening and closing pressures due to air flow in the mine, prior mechanisms are designed to move a mine door at slow speeds, which can waste valuable time. Further, the failure of a complex hydraulic or pneumatic mechanism may take substantial time to repair, which can severely impede operations in the mine.

There is a need, therefore, for an improved mine-door opening mechanism.

SUMMARY OF THE INVENTION

This invention is directed to a mine door system comprising a mine door comprising at least one door leaf adapted to be hinged at one side to a door frame defining an entry. The system includes an articulated door-moving mechanism that articulates between a first configuration in which the mechanism applies a relatively small door-moving force to the at least one door leaf and moves it at a first speed and a second configuration in which the mechanism applies a larger door-moving force to the at least one door leaf and moves it at a second speed less than the first speed.

The present invention is directed to a method of opening a mine door leaf installed in a mine passageway having a high pressure zone and a low pressure zone. The method comprises the steps of operating a variable-throw crank mechanism in a first configuration having a first crank length to apply a first force to the mine door leaf to move it at a first speed, operating the variable-throw crank mechanism in a second configuration having a second crank length less than the first crank length to apply a second force greater than the first force to the mine door leaf to move it at a second speed slower than the first speed, and using a resistance pressure associated with the high and low pressure zones in the mine passageway to convert the variable-throw crank mechanism from the first configuration to the second configuration.

Other objects and features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a mine door installation incorporating articulated door-moving mechanisms of this invention;

FIG. **2** is a perspective of components of one of the articulated door-moving mechanisms of FIG. **1**;

FIG. **3** is an exploded perspective of the door-moving mechanism; and

FIG. **4** is a top plan view of the door-moving mechanism showing a door leaf in a fully-closed position;

FIG. **4**A is an enlarged portion of FIG. **4** with parts removed to illustrate operation of a crank mechanism;

FIG. **5** is a top plan view of the door-moving mechanism showing the door leaf and crank mechanism after the door has moved through an initial-opening segment;

FIG. **5**A is an enlarged portion of FIG. **5** with parts removed to illustrate operation of the crank mechanism; and

FIGS. **6**-**9** are top plan views illustrating a sequence of door movement from the position shown in FIG. **5** to a fully-open position and back to a fully-closed position, portions being broken away to show details and principles of the action of the crank mechanism.

Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

Referring now to the drawings, FIGS. **1** and **2** illustrate an exemplary mine door system of this invention, generally designated **20**. The system is adapted to be installed in a mine passageway **14** that has a high pressure zone **16** and a low pressure zone **18**. In normal mine operation, the high pressure zone **16** (which is in fresh air) is on the side of the mine door system **20** most adjacent the mine entrance or in a passageway that during normal flow of air does not receive air that has passed along the mine face, and the low pressure zone **18** is the side of the mine door system **20** closest to the mine face where ore or mineral is being mined. However, the door system **20** can be placed in the return air of a mine (downstream from the mine face), in which case the high pressure zone **16** would be on the side of the door system closest the mine face, and the low pressure zone would be on the opposite side of the door system.

The mine door system **20** comprises a mine door, generally designated **30**, adapted to be mounted on a door frame **32** installed in the passageway **14**. The door frame **32** defines an entry and comprises a pair of telescoping columns **36** at opposite sides of the door frame and a lintel **40** spanning the columns. The door **30** comprises first and second door leafs **30**A, **30**B mounted on respective columns **36** by hinges **44**, for example, for back and forth swinging movement of the door leafs between a fully-closed position (FIGS. **1** and **4**) and a fully-open position (FIG. **7**). When the door leafs **30**A, **30**B are fully closed, they are generally coplanar. Seals (not shown) are secured to the bottom edges of the door leafs **30**A, **30**B to seal against air flow between the leafs and the mine floor. An astragal seal **50** is secured along the free-swinging vertical edge of the first door leaf **30**A to seal against air flow between the two leafs of the door. Desirably (but not necessarily), the seal **50** is secured to the high-pressure face of the first door leaf **30**A and overlaps the high-pressure face of the second door leaf **30**B when the two door leafs are fully closed. The opening and closing of the two door leafs **30**A, **30**B are sequenced to preserve the astragal seal. Thus, in an opening sequence, the first door leaf **30**A carrying the astragal seal **50** preferably starts to open slightly before or at the same time as the second door leaf **30**B starts to open and, in a closing sequence, the second door leaf closes before the first door leaf so that the astragal seal on the first door leaf seals properly against the high-pressure face of the second door leaf. Details on mine door and frame construction as well as other aspects of mine door usage are provided in U.S. Pat. No. 4,911,577 (Mine Door System); U.S. Pat. No. Re. 34,053 (Mine Door System); U.S. Pat. No. 5,168,667 (Door System for Mine Stopping); U.S. Pat. No. 5,222,838 (Power Mine Door System); U.S. Pat. No. 5,240,349 (Power Mine Door System); U.S. Pat. No. 6,032,986 (Door System for Mine Stopping); U.S. Pat. No. Re. 36,853 (Mine Door System); U.S. Pat. No. 6,164,871 (Mine Stopping Having a Swinging Door) and U.S. Pat. No. 6,425,820 (Mine Door Power Drive System), all of which are assigned to Jack Kennedy Metal Products, Inc. of Taylorville, Ill., all of which are hereby incorporated herein by reference.

The technology of the present invention can be applied to both single-leaf door installations and double-leaf door installations.

The mine door system **20** also includes first and second articulated door-opening mechanisms, generally designated **54**, **56** (FIG. **1**), for moving respective first and second door leafs **30**A, **30**B from their fully-closed positions to their fully-open positions. In the illustrated embodiment, the door-opening mechanisms **54**, **56** are substantially identical, so only the first mechanism **54** will be described in detail. However, in other embodiments, the second door-opening mechanism **56** may differ from the first mechanism **54**.

Referring to FIGS. **2** and **3**, the first door-opening mechanism **54** is an articulated mechanism comprising a mechanical link **60** having a first end **62** connected to the door leaf **30**A for rotational movement relative to the door leaf about a first generally vertical axis **66**. In the illustrated embodiment, the mechanical link **60** is elongate and comprises first and second elongate rigid members, such as steel bars **70**, **72** of rectangular cross section, secured together end-to-end by a suitable fastener (e.g., a bolt **76**) for pivotal movement about an axis **80** extending in a generally horizontal plane generally transversely with respect to the bars. The first end **62** of the mechanical link **60** has a pivot connection **84** to a bracket **88** affixed to the first door leaf **30**A for rotational movement of the link about the vertical axis **66**. The pivot connection **84** comprises a clevis **90** threaded on a threaded shaft **92** extending endwise from the second rigid member **72** of the mechanical link **60**. The arrangement is such that the effective length of the mechanical link **60** can be adjusted by threading the clevis **90** along the shaft **92**. The mechanical link **60** and its connection to the door leaf **30**A can have other configurations without departing from the scope of this invention.

The first door-opening mechanism **54** also includes a crank, generally designated **100**, connected to the mechanical link **60** toward a second end **102** of the mechanical link **60**, and preferably immediately adjacent the second end of the link, for rotational movement relative to the mechanical link about a second generally vertical axis **106** spaced from the first vertical axis **66** (see FIGS. **2-4**). An actuator, generally indicated at **110**, rotates the crank **100** through an angular range of crank movement about a third generally vertical axis **112** spaced from the second axis **106** thereby to apply, via the mechanical link **60**, an opening/closing force to the door leaf **30**A.

As illustrated in FIG. **4**, the actuator **110** comprises a drive unit **120** that includes a motor **124** and a speed reducer **126** connected by a coupling **128**. An endless belt **130** connects a drive member comprising a sprocket **132** on the output shaft of the speed reducer **126** to a driven member comprising a sprocket **140** affixed to the crank **100**. In the illustrated embodiment, the motor **124** is a non-reversing electric motor; the speed reducer **126** is a unit having an output speed in a suitable range such as 0.5-6 rpm, or 3-6 rpm, or about four rpm; and the endless belt **130** is a chain belt in mesh with the sprockets **132**, **140**. Desirably, a brake is provided on the motor **124** and is applied when the motor is off to prevent the door leaf **30**A from coasting beyond a desired point (e.g., past dead-center positions in which the door is fully open and fully closed). The coupling **128** between the motor **124** and the speed reducer **126** may include a slip clutch to protect the motor and speed reducer in the event the door leaf **30**A becomes jammed or blocked. The output shaft of the speed reducer **126** is directed in an upward direction, which is desirable in case the shaft seal fails. Other drive configurations are possible.

In the illustrated embodiment, the crank **100** is a variable-throw (variable-length) crank comprising first and second crank arms **150**, **154** connected for pivotal movement relative to one another about a fourth generally vertical axis **158** located between the second and third vertical axes **106**, **112**, as viewed in FIGS. **2** and **3**. An upper shaft **164** extends up from the first crank arm **150** adjacent a first end of the arm through a hub **168** on the driven sprocket **140** and through bearings **170** on opposite sides of the sprocket. The upper shaft **164** has a central axis coincident with the third vertical axis **112** and is keyed to the hub **168** so that the shaft and sprocket rotate in unison about the third axis. A lower shaft **176** extends down from the first crank arm **150** adjacent a second end of the arm through bearings **178** received in an opening **182** in the second crank arm **154** adjacent a first end of the second crank arm. The lower shaft **176** has a central axis coincident with the fourth pivot axis **158** and rotates freely relative to the second crank arm **154** about the fourth axis. The range of such relative rotational movement is limited by a stop mechanism comprising a first stop member **180** on the first crank arm **150** and a second stop member **184** on the second crank arm **154**. A shaft **190** extends down from the second crank arm **154** adjacent a second end of the arm through bearings **194** received in an opening **198** in the mechanical link **60** adjacent the second end **102** of the arm. The shaft **190** has a central axis coincident with the second pivot axis **106** and rotates freely relative to the mechanical link **60** about the second axis.

As will be described in more detail below, the variable-throw crank **100** articulates between a first configuration (e.g., FIGS. **4** and **4**A) in which it has a longer length and applies a relatively smaller door-moving force to its respective door leaf **30**A, **30**B and a second configuration (FIGS. **5** and **5**A) in which the mechanism has a shorter length and applies a larger door-moving force to the door leaf. (The "length" of the crank **100** as used herein is the straight-line distance between the second and third pivot axes **106**, **112**. Compare FIG. **4**A in which L1 represents the "length" of the crank **100** in its stated first (longer) configuration, and FIG. **5**A in which L2 represents the "length" of the crank **100** in its stated second (shorter) configuration.)

The crank **100** assumes its first or "lengthened" configuration (e.g., FIGS. **4** and **4**A) when the door leaf **30**A is under a relatively light load condition. In this configuration, the second, third and fourth pivot axes **106**, **112**, **158** are substantially in alignment, and the length or "throw" of the crank **100** is increased to a "full-throw" or "full-length" condition. As a result, rotation of the crank about the third vertical axis **112** generates less door-opening force.

The crank **100** assumes its second or "shortened" configuration (FIGS. **5** and **5**A) during conditions when the door leaf **30**A is under a relatively heavy load condition. In this second configuration the second, third and fourth vertical axes **106**, **112**, **158** are substantially out of alignment and the length or "throw" of the crank **100** is correspondingly reduced to a "reduced-throw" or "reduced-length" configuration. As a result, rotation of the crank about the third axis **112** automatically generates more door-opening force.

Importantly, the change of the length of the crank **100** also affects the speed at which the door leaf **30**A moves. In this regard, the speed at which the door moves is a function of both the angle of the crank **100** (as it rotates around axis **112**) and the length of the crank. In particular, the crank-angle component of speed is substantially zero when the crank angle is zero, i.e., when the first, second, third, and fourth vertical axes **66**, **106**, **112**, **158** are substantially aligned ("dead-center"). Desirably, the crank assumes a first dead-center position when the door leaf **30**A is fully closed (FIGS. **4** and **4**A) and a second dead-center position when the door leaf is fully open (FIG. **7**). The crank-angle component of the door-moving speed increases smoothly from zero as the crank **100** rotates away from its first dead-center position up to a maximum value and then decreases smoothly back to zero as the crank **100** rotates to its second dead-center position. Similarly, the crank-angle component of the door-moving speed increases smoothly from zero as the crank **100** rotates away from its second dead-center position up to a maximum value and then decreases smoothly back to zero as the crank **100** rotates back to its first dead-center position. The crank-throw component of speed varies from a relatively large value when the crank **100** is in its first (longer) configuration and a smaller value when the crank is in its second (shorter) configuration. The speed at which the door moves at any given time is a function of the crank-angle speed component and the crank-throw speed component.

A holding device **200** holds the variable-throw crank **100** in its first (full-throw) configuration in which the second, third and fourth vertical axes **106**, **112**, **158** are substantially in alignment. In the illustrated embodiment, the holding device **200** is a helical torsion spring (also designated **200**, for convenience) having a central vertical axis generally coincident with the fourth vertical axis **158**. The spring **200** has first and second end portions **204** bent vertically for reception in vertical sleeves **208** mounted on the first and second crank arms **150**, **154**, respectively (see FIGS. **2** and **3**). The spring **200** is configured to hold the crank **100** in its first (full-throw) configuration until the force required to open the door leaf **30**A exceeds a predetermined amount, as during heavy load conditions, at which point the spring will deflect resiliently (i.e., wind up) under the load from its "home" configuration to allow the crank to move to its second (reduced-throw) configuration. When the force required to open the door leaf falls below the predetermined amount, the spring **200** will return (i.e., unwind) under its own resilient power to its "home" configuration to force the crank **100** back toward its first configuration (full-throw) configuration. Other types of springs and spring arrangements can be used for holding the crank **100** in a full-throw (increased-throw) configuration during light-load conditions while allowing the crank to move to a reduced-throw configuration during heavier load conditions. The amount of force required to deflect the spring **200** will depend on the configuration of the spring and its spring characteristic. The force to be exerted by the spring on the door leaf **30**A is selected based on such factors as the size of the door leaf, operating speed, friction, and the power on the drive. The spring should have sufficient power to straighten the crank by overcoming the various frictions in the system, such as door seal flaps dragging on the floor of the mine, after the air load on the door leaf is substantially or entirely eliminated.

Devices other than a torsion spring can be used for holding the crank **100** in its first configuration while allowing the articulated door-moving mechanism to move toward its second configuration when the force for opening the door exceeds a predetermined amount. By way of example, other types of springs can be used, such as a gas spring, coil spring, leaf spring, or other spring arrangement. A non-spring powered or fixed mechanical mechanism can also be used, such as a cam mechanism, or an eccentrically-operated mechanism, or a motor or other powered device which positively moves the crank **100** between its first and second configurations.

The door-opening mechanism **54** is mounted in an enclosure or housing **220** secured in suitable fashion (e.g., welded or fastened) to the lintel **40** of the door frame **32**. The housing **220** extends like a cantilever from the lintel **40** and is supported at its free (outer) end by a brace **224**.

A suitable control system **250** (FIG. **4**) is provided for controlling the operation of the motor **124** of the door-moving mechanisms **54**. (The same or similar control system is used for controlling the operation of the door-moving mechanism **56**.) In one embodiment, the control system **250** is mounted close to the mine door **30** for operation by a person near the door. The control system can include a programmable processor for programming the opening and closing sequence and/or speeds of the door leafs. The control system may also be used to control signal lights and alarms associated with the mine door.

FIGS. **4-9** are schematic views illustrating a typical opening sequence of the first door leaf **30**A.

FIG. **4** shows the first door leaf **30**A in its fully closed position in which the door leaf is closely adjacent or bearing against the lintel **40**. In this position, the crank **100** is in its first (full-throw) configuration and in (or close to) a dead-center position in which the first, second, third and fourth vertical axes **66**, **106**, **112**, **158** are substantially aligned; and the fourth axis **158** at the connection between the two crank arms **150**, **154** is located between the second and third axes **106**, **112**. In this position, the air-pressure differential across the door **30** exerts a strong static force resisting movement of the door leaf **30**A away from its fully-closed position.

FIGS. **5** and **5**A show the door leaf **30**A after the motor **124** has been actuated to rotate the driven sprocket **140** and crank **100** a short distance in a counterclockwise direction (as indicated by the arrow **230**) about the third axis **112** through a relatively small crank angle increment. The rotational movement of the crank **100** through this increment is transmitted to the mechanical link **60** which moves the door leaf **30**A through an initial-opening segment of movement. The resistance pressure against the door leaf **30**A during this segment is relatively large and exceeds the amount required to deflect the spring **200**. In this regard, the resistance pressure against the door leaf **30**A when the door leaf is in its fully-closed position is due to the static pressure differential across the door leaf. There is no velocity pressure component, because there is no air flow past the door leaf. As the door leaf starts to open and air begins to flow past the leaf, the resistance pressure actually increases due to a velocity pressure component added to the static pressure component. In response to the relatively large pressure resistance, the second crank arm **154** rotates against the urging of the spring **200** about the fourth axis **158** in a counterclockwise direction relative to the first crank arm **150** toward the second (reduced-throw) configuration of the crank **100**. The shortened crank **100** automatically results in the application of a greater door-opening force to the door leaf **30**A and a corresponding reduction in the crank-throw speed component. It will be observed that the mechanical link **60** remains generally perpendicular to the plane of the door leaf **30**A during this segment of movement for maximum efficiency. Also, the crank action causes the speed at which the door leaf **30**A moves to increase smoothly from zero as it moves away from its fully-closed position.

FIG. **6** shows the door leaf **30**A after the motor **124** has rotated the sprocket **140** and crank **100** in a counterclockwise direction about the third vertical axis **112** through another crank angle increment of movement. As the crank **100** moves through this increment, the rotational movement of the crank is transmitted to the mechanical link **60** to move the door leaf **30**A through a mid-opening segment of movement. The resistance pressure against the door during this segment is substantially less than the resistance pressure during the initial-opening segment of movement and is less than the amount required to deflect the spring **200**. As a result, the crank **100** returns under the bias of the spring to its first (full-throw) configuration. The longer throw of the crank **100** automatically results in the application of a smaller door-opening force to the door leaf **30**A and a corresponding increase in the crank-throw speed component. As a result, the speed at which the door opens automatically increases, which is desirable.

FIG. **7** shows the door leaf **30**A after the motor **124** has rotated the sprocket **140** and crank **100** in a counterclockwise direction about the third vertical axis **112** through another crank angle increment of movement. As the crank **100** moves through this increment, the rotational movement of the crank is transmitted to the mechanical link **60** to move the door leaf **30**A to move the door leaf **30**A through a final-opening segment of movement to a fully-open position in which the crank **100** is again in a dead-center position (its second dead-center position). The resistance pressure against the door leaf during this final-opening segment is typically relatively small, i.e., less than the amount required to deflect the spring **200**. As a result, the crank **100** remains in its first (full-throw) configuration. The crank action causes the speed at which the door leaf **30**A moves to decrease smoothly down to zero as it approaches its fully-open position.

To move the door leaf from its fully-open position (FIG. **7**) back to its fully-closed position (FIG. **4**), the motor **124** is operated to rotate the sprocket **140** and crank **100** in the same (counterclockwise) direction about the third axis **112** through an initial-closing segment (FIG. **8**), a mid-closing segment (FIG. **9**), and a final-closing segment. The crank action causes the speed at which the door leaf **30**A moves to increase smoothly from zero to a maximum speed as it moves away from its fully-open position and then to decrease smoothly to zero as it reaches its fully-closed position. During closing movement, the crank will normally stay in its second (full-throw) configuration since less power is needed to close the door.

Thus, in the illustrated embodiment, the variable-throw crank **100** is configured to pivot in one direction along a circular path of about 360 degrees as the door leaf moves from its fully-closed position to its fully-open position and then back to its fully-closed position. In other embodiments, a reversing motor (or other reversing drive) is used to rotate the crank (e.g., 180 degrees) in one direction to open the door leaf and in the opposite or reverse direction (e.g., 180 degrees) to close it.

It will be observed from the above that the operation of the crank **100** moves the door leafs **30**A, **30**B from a zero speed (at the first dead-center position) to a relatively high speed and back to a zero speed (at the second dead-center position) as the leafs move between their fully-open and fully-closed positions. Significantly, the transitions between these speeds are infinitely smooth to reduce jarring forces to the door system and surrounding structure. The crank can be a fixed-length crank or a variable-length crank to achieve this advantage, and this invention contemplates the use of both such embodiments.

The pivot or knuckle connection **76** between the two rigid members **70**, **72** of the mechanical link **60** allows limited vertical movement between the door leaf **30**A and the crank **100** as the door leaf opens and closes to avoid binding of the crank bearings **170**, **178**, **194**.

The operation of the second door-opening mechanism **56** to open and close the second door leaf **30**B is similar to the operation of the first door-opening mechanism **54** described above. As note previously, the opening and closing of the door leafs **30**A, **30**B are preferably sequenced such that the door leaf **30**A with the astragal seal **50** starts its initial movement at least slightly before the initial opening movement of the other door leaf **30**B to avoid damage to the seal, and such that the door leaf **30**A with the astragal seal arrives back at its fully-closed position at least slightly after the other door leaf **30**B has reached its fully-closed position to insure proper sealing.

The crank design of this invention provides advantages over conventional hydraulic or pneumatic door-operating systems. By way of example, the crank design is less complex and less costly. Additionally, the action of the variable-throw crank allows greater operating speed because it automatically reduces the momentum of the door leaf as it stops and starts. The crank design insures a very smooth transition from zero speed with corresponding low reaction back to the frame **32** as the door leaf gains momentum, a very high mid-stroke speed for a quick opening time, and a very smooth transition from high speed back to zero speed with little momentum delivered to the frame. The smoothness in transitioning between speeds (i.e., smooth acceleration and deceleration) reduces the risk of damage to the door frame **32**, to the surrounding structure, and to the seals on the door leafs. Further, the crank design provides a large advantage in mechanical advantage or leverage when the door leaf is starting to open against a heavy air load. Then, when the air load is reduced (e.g., due to the door being open a little and the air able to flow through the opening), the speed of door movement automatically increases, trading thrust or force for speed. Also, the line of force exerted by the crank **100** and mechanical link **60** is more perpendicular (closer to perpendicular) to the door leaf when it is opening, and less perpendicular (farther away from perpendicular) as the door leaf is more fully opened. This is advantageous because the better the vector against the door leaf the more efficient the design, i.e., it takes less force to open the door leaf if you are pushing squarely against it, and more force if you are vectored off at an angle to it. After the air load is overcome and greater force is not required, the door trades the square vector for a more oblique one so the door speeds up and automatically trades force for speed as the load is reduced. As a result, the door leaf moves more slowly from its fully-closed position to its fully-open position and more rapidly from its fully-open position to its fully-closed position. By way of example but not limitation, the door leaf **30**A may open in about eight seconds as the crank rotates through a first segment of about 180 degrees and close in about six seconds as it moves through a second segment of about 180 degrees.

It will also be observed that the connection of the mechanical link **60** to the door leaf **30**A is more toward the center of the entry when the door is closed and swings to the side as the door is opened. This design is advantageous in that the mechanical and connection hardware is moved out of the center of the entry to provide greater clearance through the open entry but is still located to push at a point some distance from the hinge to get a significant mechanical advantage.

The control system **250** controls the operation of the motors **124** of both door-opening mechanisms **54**, **56**, preferably independent of one another. As a result, the control system **250** is able to control the movement of each door leaf independent of the other door leaf to achieve the desired opening and closing times of each door leaf, the sequence of movement of one door leaf relative to the other door leaf, and any other variations in movement that may be desirable.

The motors **124** can be reversing motors rather than non-reversing motors. However, a non-reversing motor arrangement is typically less expensive. Further, rotating the crank **100** in one direction only has a leverage advantage. If the crank is arranged to turn so that the throw starts to move outward, toward the center of the entry as the mechanism starts to open the door, the crank **100** and mechanical link **60** automatically start to get a better purchase through a more perpendicular vector to the door leaf. Also, since the crank **100** keeps turning in the same direction to close the door leaf that it did to open it, the design automatically trades the opening force vector for a closing speed vector, which is desirable. Force is not needed to close the door leaf, only to open it since the pressure differential across the door leaf tends to close it.

As previously noted, in the illustrated embodiment the door-opening mechanisms **54**, **56** are substantially identical. However, in other embodiments, the second door-opening mechanism **56** may differ from the first mechanism **54**. By way of example, the first door-opening mechanism **54** may include a variable-length crank mechanism, as described above, and the second door-opening mechanism may not include a variable-length crank mechanism. In that case, the first mechanism could be operated to open the first door leaf **30**A first to relieve the air load on the door, and the second mechanism then operated.

Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

When introducing elements of the present invention or the preferred embodiments(s) thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions, products, and methods without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A method of opening a mine door leaf installed in a mine passageway, said passageway having a first pressure zone on a first side of said door leaf and a second pressure zone on a second side of said door leaf, the first pressure zone having a pressure that is higher than a pressure of the second pressure zone, the method comprising:

operating a variable-throw crank mechanism in a first configuration having a first crank length to apply a first force to the mine door leaf to move the mine door leaf at a first speed,

operating the variable-throw crank mechanism in a second configuration having a second crank length less than the first crank length to apply a second force greater than the first force to the mine door leaf to move the mine door leaf at a second speed slower than the first speed, and

using a resistance pressure associated with the first and second pressure zones in the mine passageway to convert the variable-throw crank mechanism from the first configuration to the second configuration.

2. A method as set forth in claim **1** further comprising converting the variable-throw crank mechanism from the second configuration to the first configuration in response to a decrease in said resistance pressure and using said first force to open the mine door leaf at said first speed following the decrease in said resistance pressure.

3. A method as set forth in claim **1**, wherein said method further comprises rotating said variable-throw crank mechanism through approximately 360 degrees in one direction to move the door leaf from a fully-closed position to a fully-open position and then back to said fully-closed position.

4. A method as set forth in claim **1**, wherein said method further comprises rotating said variable-throw crank mechanism through approximately 180 degrees in a first direction to move the door leaf from a fully-closed position to a fully-open position and then rotating the variable-throw crank mechanism through approximately 180 degrees in a second direction opposite to the first direction to move the door leaf back to said fully-closed position.

5. A method as set forth in claim **1** wherein the step of using said resistance pressure to convert the variable-throw crank mechanism from the first configuration to the second configuration includes using a velocity pressure component associated with air flow past the door leaf as the door leaf opens to convert the variable-throw crank mechanism from the first configuration to the second configuration.

6. A method as set forth in claim **1** wherein the variable-throw crank mechanism is converted from the first configuration to the second configuration as the door leaf moves through an initial opening movement.

7. A method as set forth in claim **6** further comprising converting the variable-throw crank mechanism from the second configuration to the first configuration in response to a decrease in said resistance pressure following movement of the door leaf through the initial opening movement.

8. A method as set forth in claim **1** further comprising converting the variable-throw crank mechanism from the second configuration to the first configuration in response to a decrease in said resistance pressure following movement of the door leaf through an initial opening movement.

9. A method as set forth in claim **8** wherein the step of converting the variable-throw crank mechanism from the second configuration to the first configuration comprises using a spring.

10. A method as set forth in claim **9** wherein the step of using said resistance pressure to convert the variable-throw crank mechanism from the first configuration to the second configuration comprises overcoming a force applied by the spring biasing the variable-throw crank mechanism toward the first configuration.

11. A method as set forth in claim **10** further comprising decreasing a speed at which the door leaf rotates as the door leaf approaches a fully-open position while the variable-throw crank mechanism remains in the first configuration and is driven by a motor.

12. A method as set forth in claim **11** further comprising using a motor to rotate the variable-throw crank mechanism to move the door leaf from a closed position to the fully-open position and from the fully-open position back to the closed position without reversing the direction the motor rotates the variable-throw crank mechanism.

13. A method as set forth in claim **1** further comprising using a motor to rotate the variable-throw crank mechanism to move the door leaf from a closed position to an open position and from the open position back to the closed position without reversing a direction the motor rotates the variable-throw crank mechanism.

14. A method as set forth in claim **13** wherein the variable-throw crank mechanism comprises first and second crank arms connected together for pivotal movement relative to one another, the first crank arm being connected between the second crank arm and the motor, the method further comprising using the motor to rotate the first crank arm in said direction through an angle of rotation of approximately 360 degrees to drive the door leaf from the closed position to the open position and from the open position back to the closed position.

15. A method as set forth in claim **14** wherein the step of converting the variable-throw crank mechanism from the first configuration to the second configuration comprises rotating the first and second crank arms relative to one another.

16. A method as set forth in claim **15** wherein variable-throw crank mechanism is biased toward the first configuration by a biasing force and wherein the step of converting the variable-throw crank mechanism from the first configuration to the second configuration comprises allowing the resistance pressure to rotate the first and second crank arms relative to one another against the biasing force.

17. A method as set forth in claim **16** wherein the resistance pressure includes a velocity pressure component associated with air flow past the door leaf as the door leaf opens.

18. A method as set forth in claim **17** wherein the variable-throw crank mechanism is converted from the first configuration to the second configuration as the door leaf moves through an initial opening movement.

19. A method as set forth in claim **1** wherein the variable-throw crank mechanism comprises a first crank arm, a second crank arm, a crank bearing, and a mechanical link, the first and second crank arms being connected together for pivotal movement relative to one another, the first crank arm being connected between the second crank arm and a motor configured to rotate the variable-throw crank mechanism, the second crank arm being connected between the first crank arm and the mechanical link, the crank bearing being positioned at an end of at least one of the first and second crank arms to facilitate the pivoting movement of said at least one of the crank arms, wherein the mechanical link comprises a pair of members connected by a connection allowing pivoting movement of the members relative to one another about a generally horizontal axis, the method further comprising:

allowing the mechanical link to pivot at said connection in response to vertical movement of the door leaf relative to the variable-throw crank mechanism to limit binding of the crank bearing.

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